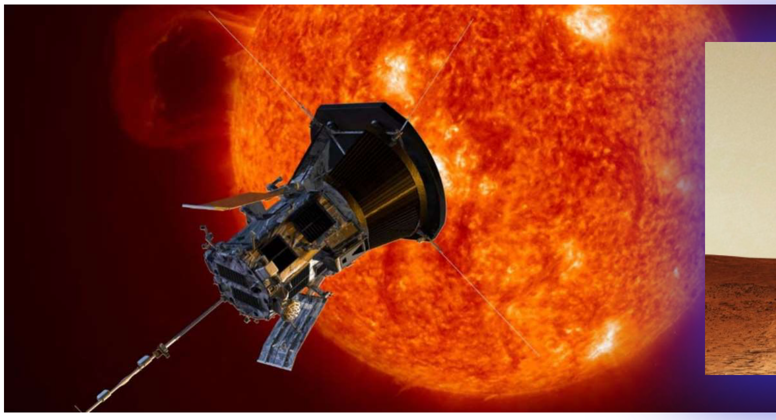
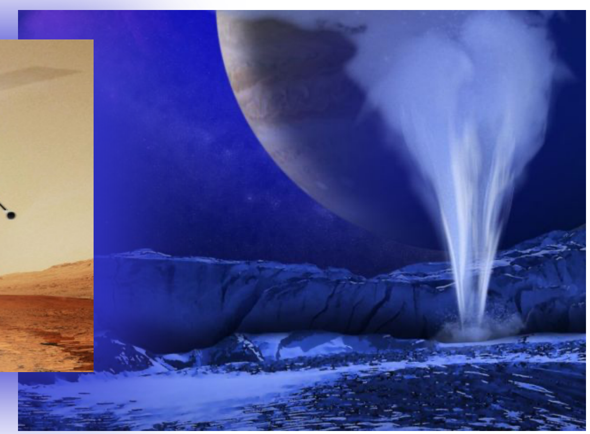
National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Thermal Cycling Fatigue Life Qualification for Earth and MARS and Deep Space Mission





Anupam Choubey
Thermo-Mechanical Reliability Lead

John Forgrave
Group Supervisor

Office of Safety and Mission Success
Jet Propulsion Laboratory, NASA
California Institute of Technology, Pasadena, CA

Outline

- Mission Overview
- Thermal Environments
- Qualification Methodology
- Case Studies

National Aeronautics and
Space Administration

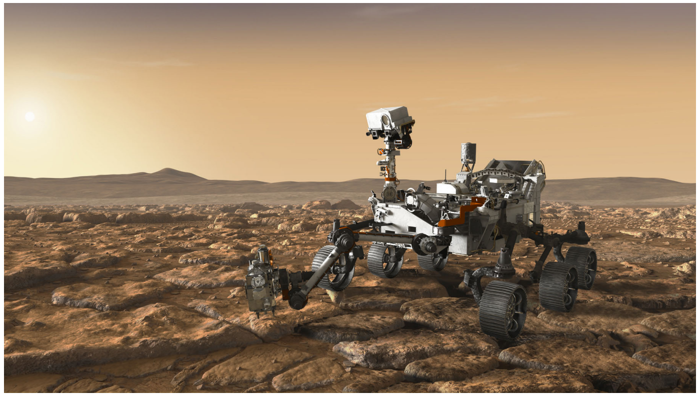
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Thermal Environments

Moon

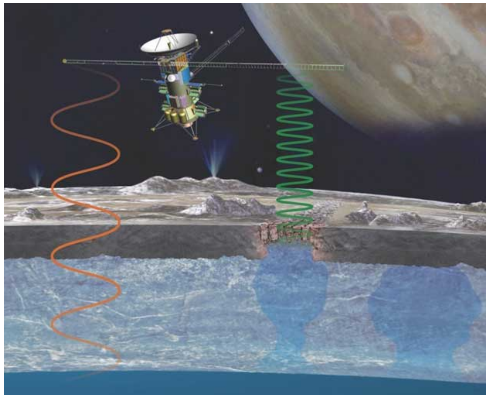
Cold: -230 C
Hot: 123C

MARS

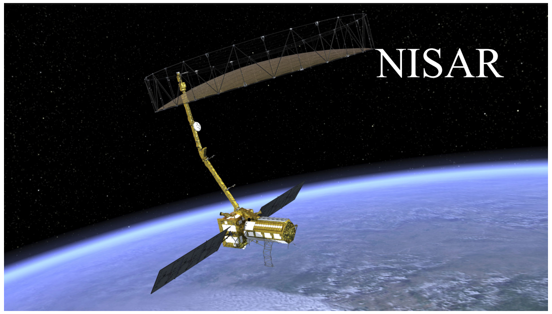


Winter Cold : -135 C
Summer Hot: + 70 C
Mission: 3 ~ 5 years

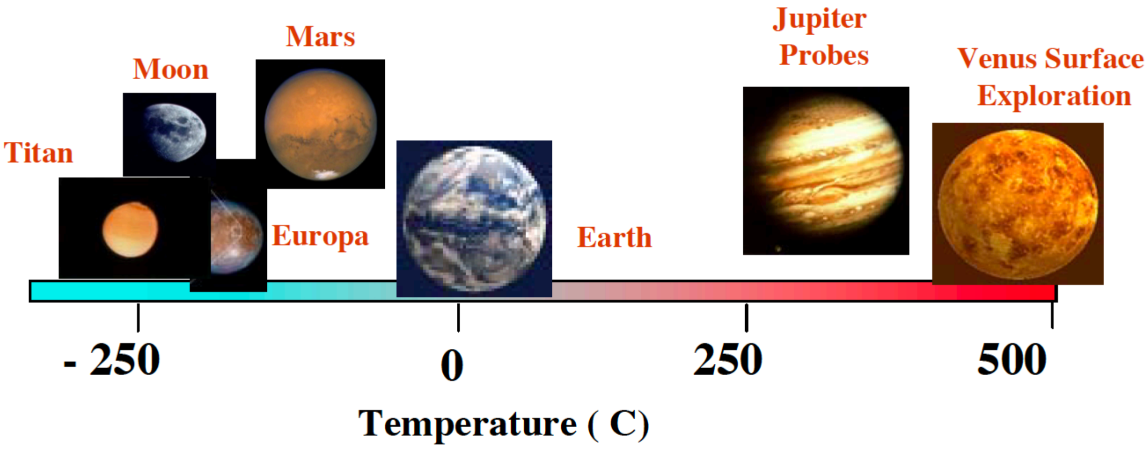
Deep Space



Europa Clipper
Cold: -240C
Hot: 195C (Venus Flyby)
Mission: 3 ~ 5 years



Earth Orbiter
14-16 times/day
3 – 4yrs mission
18000 cycles/seasons



JPL

JPL Environmental Programs

Assembly/Subsystem Testing

- Dynamic tests
  - Random vibration (include frequency survey)
  - Quasi-static loads (entry, landing)
  - Pyroshock
  - Acoustic noise (selected - large area/mass)
  - Sine sweep (grinding/drilling)
- Thermal tests
  - Thermal vacuum
  - Multipacting/ionization breakdown (corona)
  - Thermal cycling life (Fatigue)
- EMC tests
  - Conducted susceptibility/emission
  - Radiated susceptibility/emission
  - Grounding & isolation
- Environmental analyses
  - Radiation (TID, DD, SEE)
  - Venting (pressurization & depressurization)

Spacecraft System Testing

- Dynamic tests
  - Low-level random survey
  - Random vibration
  - Quasi-static loads (Launch/entry)
  - Acoustic noise
  - Pyro firing
- Thermal tests
  - Thermal vacuum (w/ thermal balance - critical h/w at FA limits during functional)
- EMC tests
  - Radiated emission
  - Radiated susceptibility
  - Self compatibility
- Environmental analyses
  - Orbital debris
  - Meteoroid (survival & shielding)
  - ESD (touch down)

Thermal cycling Qualification Program Objectives

- Ensure the flight hardware design is capable of surviving 3X thermal cycle life.
  - Includes ground, transportation, launch, cruise, entry decent & landing (EDL) and mission environments.
- Ensure all flight hardware (new and heritage) design has been assessed to withstand stresses from Thermal Expansion (CTE) mismatches
- Ensure verification is done by heritage or testing

Thermal Cycling Life (TCL) Packaging Qualification and Verification (PQV)

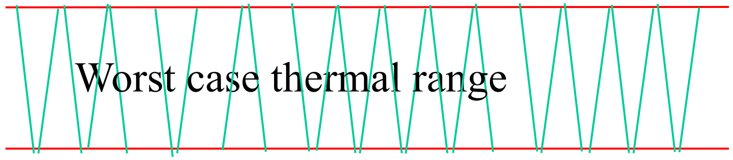
- Provides guidance early in the design to significantly **reduce likelihood of failures due to thermal cycle fatigue**
- Applicable to all spacecraft hardware
- **Identify highest risk elements** sensitive to thermal cycling fatigue, **prevent escapes**

Potential Concerns bonded joints composites paints New process solder joint interconnects connectors metal seals COTS adhesives bi-metallic or dissimilar material interfaces

PQV/TCL Vs Qual Testing

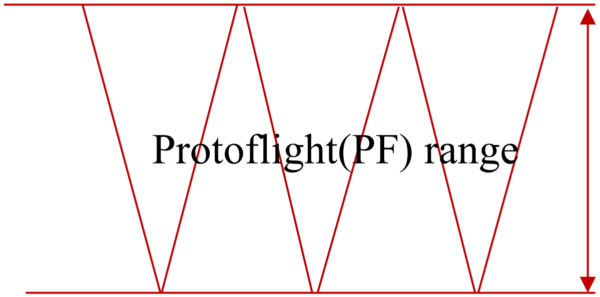
PQV/TCL: 3X life (Ground + Mission cycles)

- Early in the design phase
- Find Thermal Fatigue weaknesses
- Qualify a new design/process
- Coupons or design level testing
- Performed before qual testing to catch weakness early on before expensive qual testing



Qual testing (Typically 3-10 cycles)

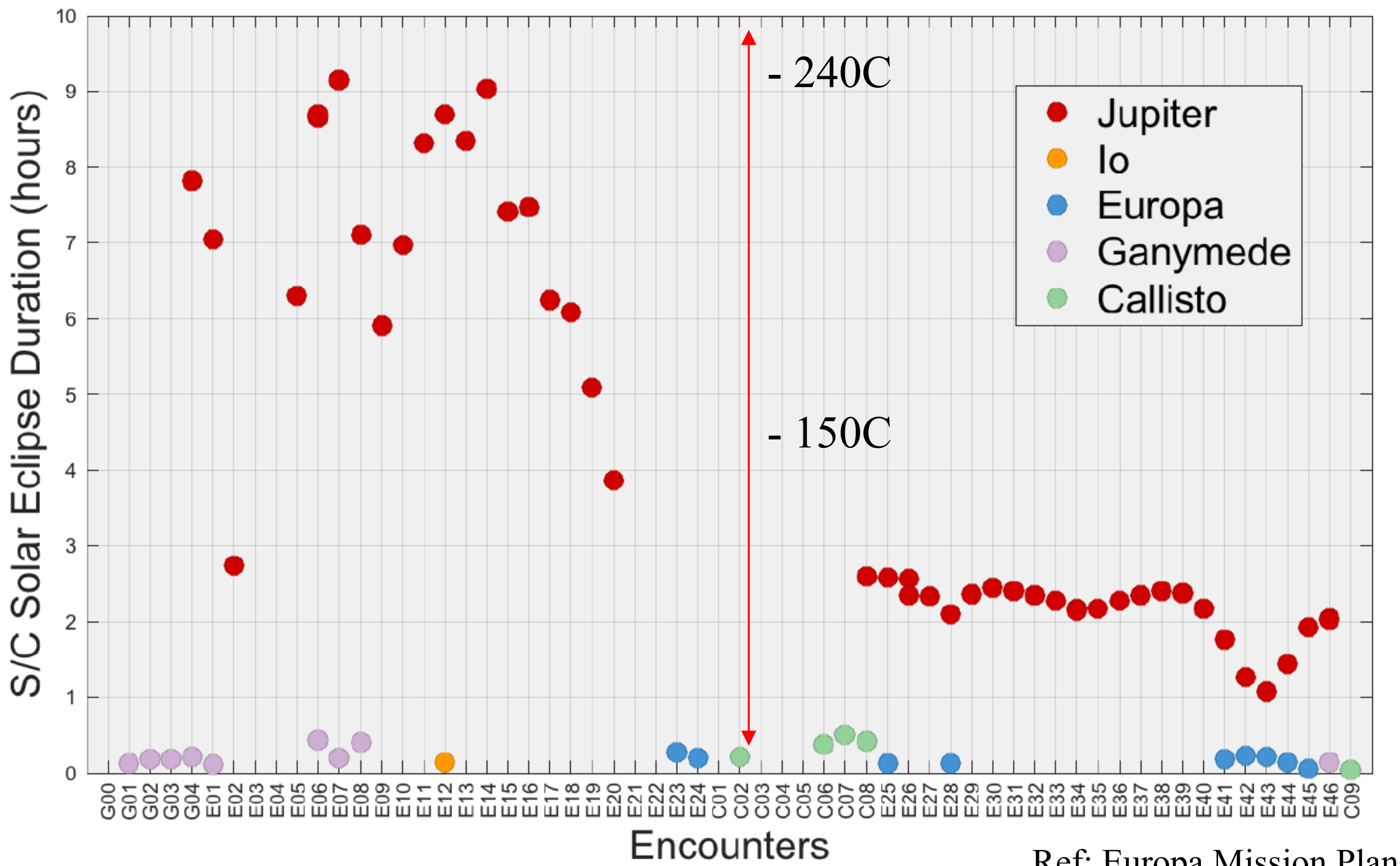
- Find Workmanship or gross design problems
- System level (EM or flight build)
- Expensive and performed before final delivery



National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Mission Plan and Thermal Environment Europa Clipper



Ref: Europa Mission Plan

- Long Eclipses results in colder temperatures and larger deltaT
- Are accounted while calculating thermal cycling life

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Thermal Cycle Estimation

					155 deltaT
Themal Events	1X	Worse Case Cold	Worse Case Hot	DeltaT (Hot-Cold)	NASA Equivalent cycles
Thermal event during board assembly (Baking, Curing..)					
Ground Power On/Off cycles	2434			20	41
Ground Thermal cycles					
Planetary protection/contamination control bake out	1	25	120	95	0
Protoflight Qual testing	3	0	70		0
Mission Power On/Off cycles	206			20	3
Mission Cruise + Orbit	120			50	12
Total 1X Cycles					57
Total 3X Cycles					170
Total 3X cycles < 200 NASA handbook requirement Criterion (@155 deltaT)					Meets

Generic Equivalent cycles calculation

$$N_2 = N_1 (\Delta T_1/\Delta T_2)^m$$

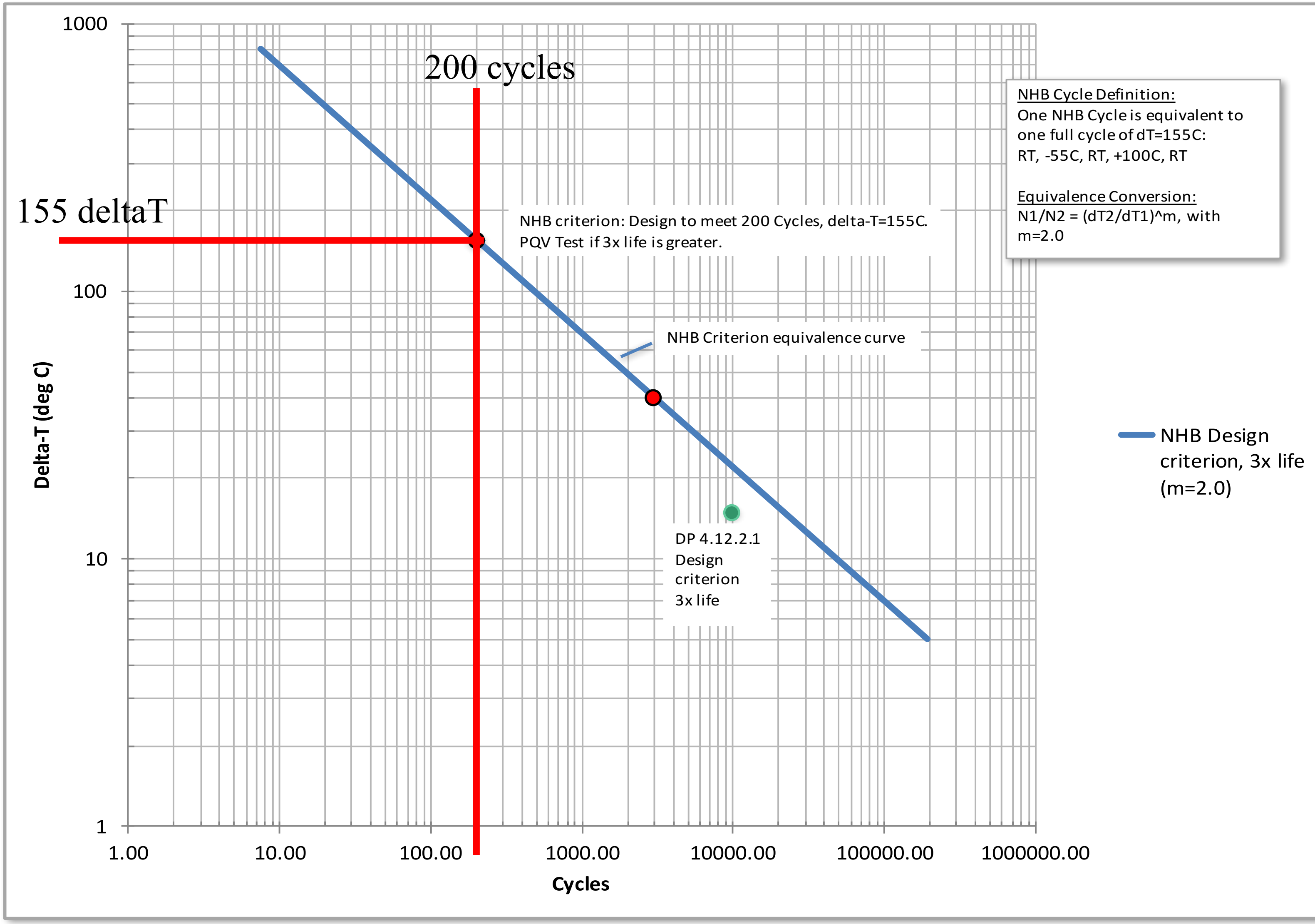
where:

- N_2 is the number of equivalent cycles over temperature range ΔT_2
- N_1 is the actual number of cyclic exposures over temperature range ΔT_1
- m is a property of the material being fatigued by cyclic thermal exposures
- m depends on failure mechanism (~2.0 for solder joints)

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Thermal Cycle Criterion



What Needs TCL/PQV testing?

- ✓ Not all hardware goes through testing
- ✓ Hardware can be qualified by analysis or heritage review.
- ✓ Assessment is done based on set criteria to eliminate the need for testing

Low risk Hardware

- Thermal Environment
  - Thermal controlled/Inside the vault
  - Thermally shielded – MLI blanketed hardware
  - Early deploy
  - One time operation
  - Benign cycles: 3 x cycles < NASA 200 cycles, -55C to 100C range

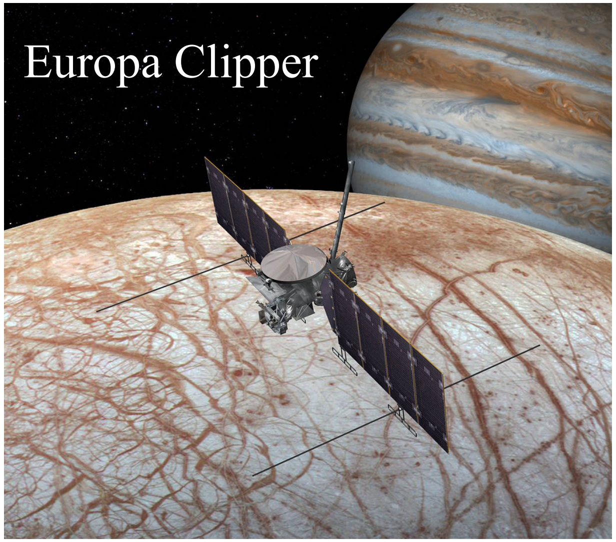
- Packaging and Material Review
  - Material: Purely structural
  - Heritage data applicable comparable to mission environment
  - Large design margin - Robust Design

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Packaging and Materials Aspects

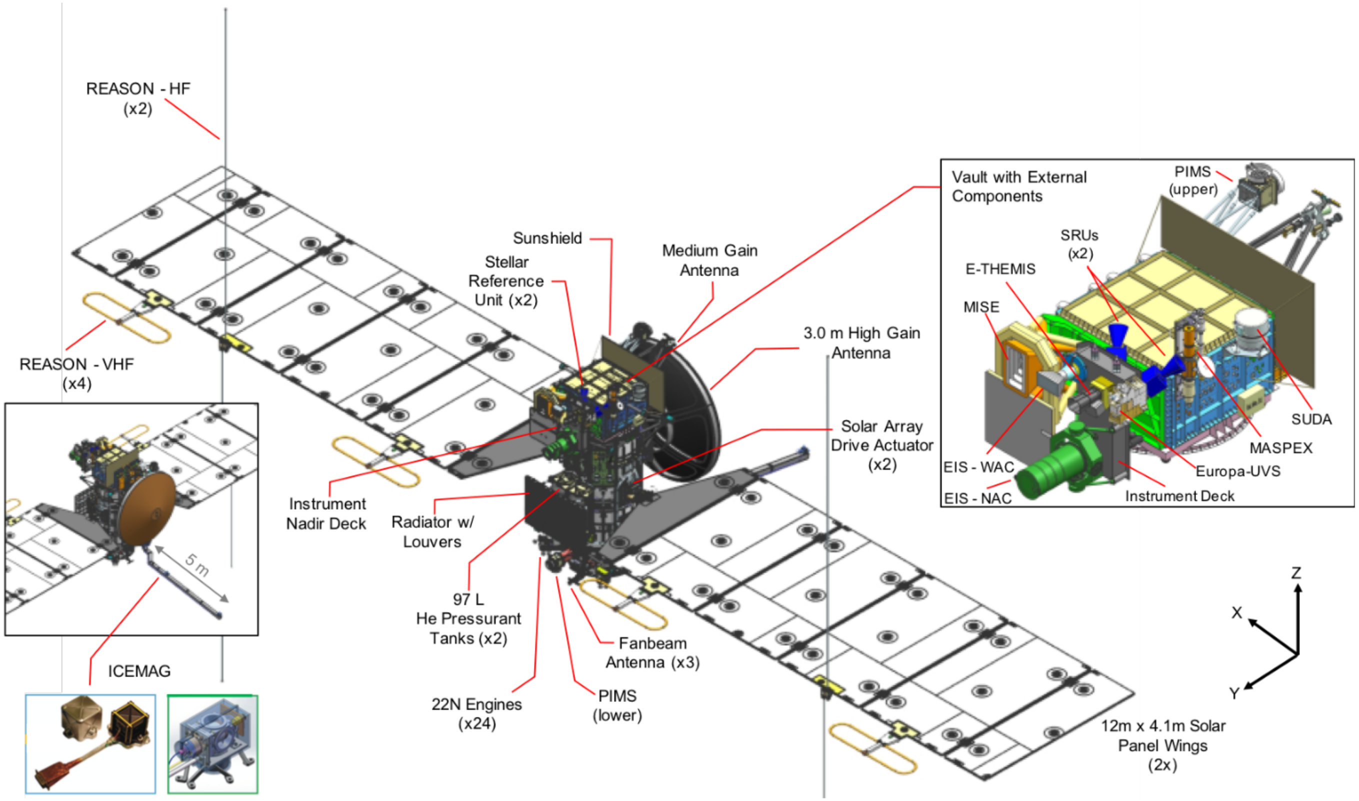
- **New process (No heritage):** Bake, assembly, underfills…
- **New material:** Adhesives change, Paints (Cryo temps)
- **Technology:** Plastic packages, COTS hardware..
- **Component packages**: Stacked components, low standoff
- **Interconnects:** Lead-free, Special solder
- **Interfaces and composite** structural elements
- **Bonded joints**



High Risk Thermal Environment

Thermal Environment related

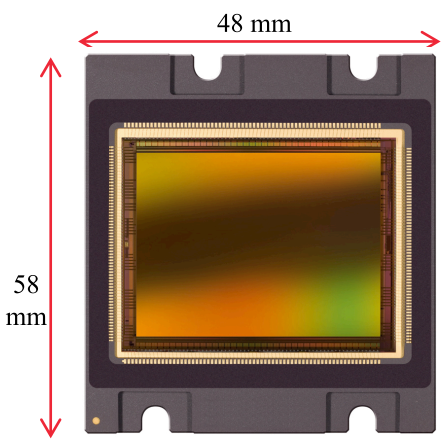
- Harsh environment (Cryogenic temperatures) (-240C) - Europa Clipper
- Externally mounted Antennas, Sensors, instruments



National Aeronautics and Space Administration

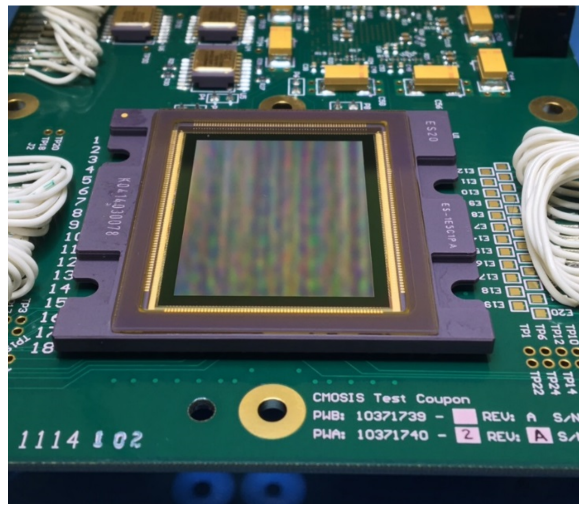
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

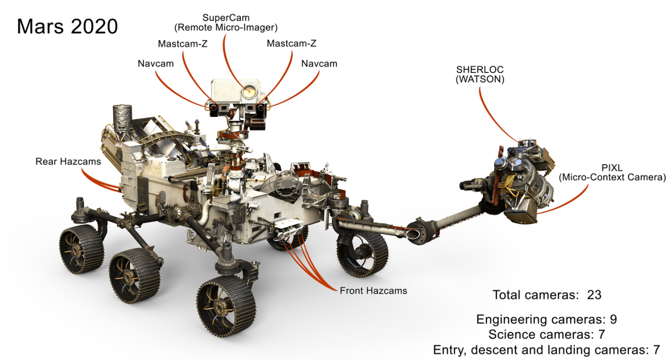
High Risk Cycling Environment



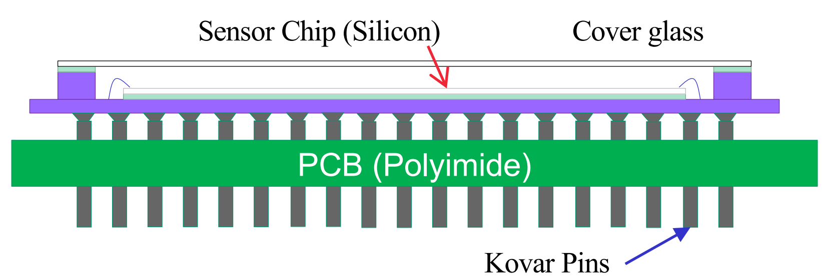
CMOSIS- 20 Megapixel Camera
CMOS Image sensor
(COTS-143 pin- Pin grid array)

>20 Cameras mounted on Rover – Panoramic Imaging, navigation, Hazard avoidance, Descent Imaging



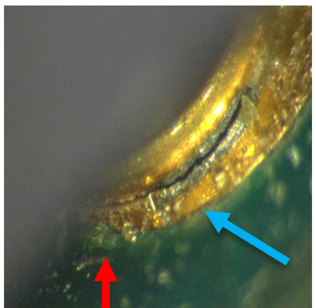


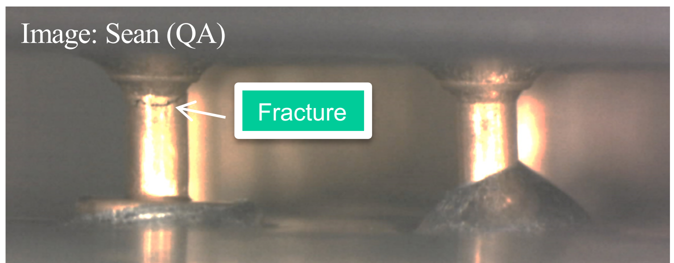
Cycle	Season	Low (°C)	High (°C)	ΔT (°C)	No. Cycles
Accelerated Risk Reduction		-135	+70	205	1530
Mars2020 PQV	Summer	-105	40	145	2115
	Winter	-135	15	145	900
Modified Seasonal Cycles	Summer	-80	+50	130	2115
	Winter 1	-115	-10	105	450
	Winter 2	-110	20	130	450



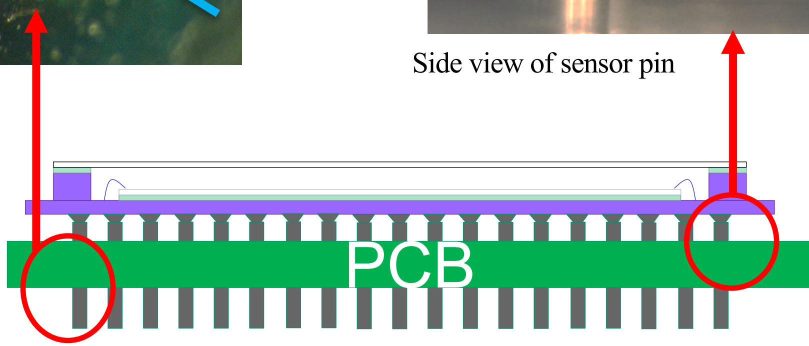
Risk Reduction Task

- **CTE mismatch causing excessive stress on corner pins resulting in fracture**
- **Risk Reduction activity**
  - **Design and assembly changes results in reduced stress and survive 3X life**

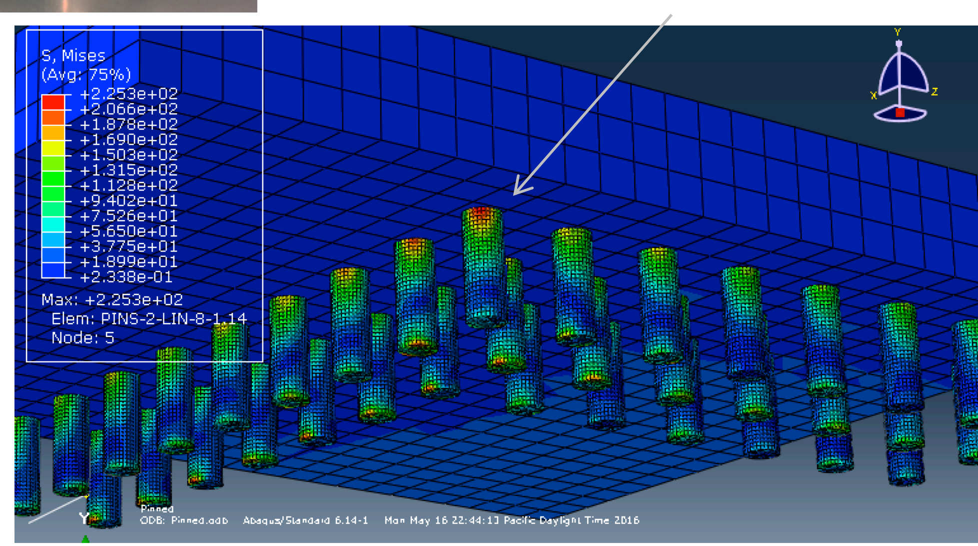




Side view of sensor pin



Maximum stress



Summary

- **Environmental Program has been an integral part of JPL missions**
- **Thermal Cycling Program has been added as part of design rules for all hardware to meet 3X life**
- **3X life requirement has proved to be sufficient to survive mission environment**
  - **Mars Rover – Working > 5X life**
- **With more and more vendors delivering hardware for JPL missions, thermal cycling life program ensures long term reliability of hardware**